Approaches for Platooning Protocols

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***Abstract*—This paper describes approaches for facilities layer protocols for platooning. These imply sharing information within a platoon of vehicles based on communication standards developed within ETSI TC ITS. Two novel ITS facilities layer protocols for platooning are proposed: Minimal and Full Platooning protocols. Deficiencies of CAM and DENM with respect to platooning are discussed. A protocol for coordinated braking is discussed. Results from a demonstration of platooning with the Minimal protocol compared to CAM/DENM are presented. It is shown that the Minimal protocol gave a lower latency of brake actuation during a hard brake manoeuvre.**

Keywords—ETSI TC ITS; Platooning; Facilities Layer Protocol; Cooperative Application; V2V Communication; Coordinated braking

I. Introduction

The paper describes three approaches for sharing information with vehicle to vehicle (V2V) communication for a platooning application; also known as a road-train. This is related to Cooperative Adaptive Cruise Control (CACC), but platooning has more collaboration between the involved vehicles. The information is communicated with the standards developed by ETSI (European Telecommunications Standards Institute) Technical Committee for Intelligent Transportation Systems (ITS). A standardised protocol for platooning, at the facilities layer of the ITS communication stack, will enable vehicles, e.g. both passenger and heavy vehicles, from different OEMs to have a common protocol for platooning. The two approaches to platooning that are outlined in the paper are:

- A new "**Full** platooning" facilities layer protocol, that addresses the needs of platooning. This protocol contains specifications for service announcement, service request (i.e. handshake) and control data in order to e.g. create and maintain platoons.
- A new "**Minimal**" facilities layer protocol that only contains control data specification, i.e. no handshake capability. The control data is the same as for the Full platooning approach above. This approach may be suitable also for CACC.

Both Full and Minimal are facilities layer protocols separate to CAM/DENM facilities layer protocols. They add data that is not available in CAM/DENM, have a fixed update rate of periodic data and enable a security scheme that is suitable for platooning.

The existing facilities layer protocols CAM and DENM are not entirely suitable to support platooning. A problem is that there is no way for a vehicle to communicate using a two-way dialogue, i.e. handshake with other vehicles. This includes identification and verification of new member that wishes to be admitted. The lack of handshake limits the possibility for starting a platoon to assume that vehicles identify each other by some other means, e.g. visual identification, and a platoon forms manually. Further, there is lack of information in the message and high overhead, e.g. due to the security scheme. Despite deficiencies, the CAM/DENM approach may be relevant since it has shorter deployment time and protocols are already standardised.

A particular challenge in platooning is that of safely coordinating braking among vehicles in an emergency brake situation. Here, the platoon vehicles must brake as much as possible while still avoiding collisions in the platoon. We present outlines for a protocol, Coordinated Emergency Brake Protocol (CEBP), for this purpose. CEBP is a part of the Platooning protocol. The relation to the ITS stack is shown in Figure 1.

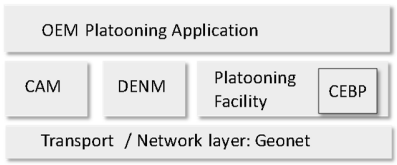

FIGURE 1: THE UPPER LAYERS OF THE ITS COMMUNICATION STACK.

The rest of the paper is organised as follows. Definitions and assumptions are made in Section II. The approaches are discussed in Section III, IV and V respectively. The coordinated brake protocol is discussed in Section VI. Results from tests, of two of the discussed protocol, are given in Section VII. Finally, conclusions and some direction for future work are given in Section VIII. A different version of this article with some more detail is found in [8].

II. Platooning Definitions and Assumptions

A platoon (or road train) is a collection of vehicles that coordinate and collaborate to reach goals such as improved safety, fuel economy and driver comfort. The leader can be

manually driven and the followers (one or more) follow the leader automatically; laterally and/or longitudinally. The target inter-vehicle gaps are small enough (e.g. <6m) that dependable communication is required for the platooning to be safe. A vehicle can only be member (as leader or follower) of one platoon at a time. A platoon capable vehicle has the technical capabilities (e.g. communication) to lead or follow in a platoon. Issues concerning positioning, e.g. accuracy and reliability of GPS, is put out of scope. A brief survey of other vehicle platooning systems is given in [1].

III. Drawback of Using CAM/DENM for Platooning

ETSI TR 102 638 V1.1.1 Annex C.2.11 [2] gives a use case of co-operative vehicle-highway automation system which resembles platooning. The use case seems to be somewhat "weaker" (e.g. lower speed, larger gaps and no handshaking) than the platooning systems described in [1]. It is inferred that the communication is based on CAM [3] and DENM [4].

The most significant information available in CAM/DENM is probably the brake signal. CAM has a varying update frequency; depending on the dynamics of the vehicle. This is detrimental to the control algorithm. CAM/DENM does not contain data fields that can be used for coordination, e.g. handshaking, of a platoon. Further, there are no unspecified data field that could be configured for use in a specific application. The resolution of the CAM brake signal is "braking" or "not braking", i.e. equivalent to an "electronic brake light". The DENM brake signal is also digital but is triggered when the vehicle is braking with a deceleration higher than 4 m/s^2, i.e. rather hard braking. For safe and efficient control, the actual deceleration reference and values (i.e. the effect of the braking on the vehicle dynamics) need to be transmitted to ensure safety.

CAM has a weak requirement regarding the age of position data (in fact any data). It is stated in [3] in Section 6.1.4.1 that "*Time required for the CAM data generation shall be less than 50 ms.*" For example, a CAM shall be sent at the latest 50 ms after new data is available from GPS. This implies added uncertainty, i.e. latency variation, for the vehicle control loop.

The movements of the vehicles in the platoon are aimed to be synchronised. Therefore, the vehicles will have the same update rate for sending CAMs. This may cause added collisions since CAMs will be generated in synchrony [5].

IV. Minimal Protocol

This approach aims to provide data for platooning without a handshake procedure. Control data messages are periodically transmitted by platooning capable vehicles. Platooning can then be done in an ad-hoc fashion with manual interaction, e.g. done by the driver by pushing a button to manually join or leave a preceding vehicle which is identified visually and detected by the existence of the platooning control data messages. This is known as CACC. No two-way interaction is done in the Minimal protocol, i.e. no handshake. Control data messages are one-way i.e. no acknowledgement from receiver back to sender. In fact, this is not possible since the identity or number of participants is not known.

The control data is the same as for Full platooning protocol, see below Section V. Control data update rate is fixed and data is transmitted as long as the vehicle wishes to stay in the platoon as a follower or leader. A difference is that the transmission of a control data messages acts as an informal service announcement. For example, a vehicle wanting to act as a leader will start to send control messages. Joining vehicles also start to send control messages and join the platoon. A vehicle leaving the platoon stops sending control messages and leaves manually. If the leader stops sending, then the platoon is dissolved. Any followers must then go to manual control.

V. Full Platooning Protocol

The Full platooning protocol implies handshaking between the provider and user(s) of the service. This is the main difference between Full and the other two approaches. Handshaking is a two-way communication and can include negotiation concerning sufficiency of technical capability and properties of the vehicle, destination planning and terms of the service such as payment. Examples of technical capability and property are remaining fuel, braking capability, loading, etc. When handshaking is complete, the identities of the users are known and the actual control data can be sent.

A. *Service Requests and Service Announcements*

Service requests are sent by vehicles wanting to enter the platoon (potential followers) and from vehicles inside the platoon who want to perform specific actions. These messages are for management of the platoon, i.e. handshaking.

Service announcements are sent by vehicle capable to lead platoons. The announcement is e.g. "I am a vehicle capable of leading a platoon, welcome to form a platoon with me" or "I am the leader of an existing platoon travelling to destination X, welcome to join". This enables potential followers in the surrounding to create or join a platoon. The repetition rate can be adapted to avoid channel congestion; the default repeat rate could be e.g. 1 s.

B. *Control Data Messages*

Data for vehicle control are sent periodically within the platoon to control the behaviour of the platoon, e.g. movements. Control data are periodically distributed in the platoon with a fixed time interval, e.g. 10 Hz. Potentially it may be negotiated as part of forming a platoon. Since data is sent periodically, the time to retransmit data is limited. Newer data will be available in the next update.

A strategy to handle lost message due to collisions is to have a fixed send window for each vehicle, depending on the position of the vehicle in the platoon, i.e. transmission slots. For example, assume that all vehicles send messages every 100 ms; but the messages are staged in slots. The leader sends during the first 10 ms slot of every 100 ms window. The second vehicle sends during the second 10 ms etc. In addition to avoiding collisions, with this scheme, every vehicle can also decide if a

message was lost or not. This assumes that each vehicle knows its relative position in the platoon and that local clocks are sufficiently synchronised. With this approach, every vehicle in the platoon knows exactly how old the last received data is. Lost messages are detected within 10 ms and vehicles can take appropriate actions due to this without any need for retransmissions or acknowledgements. Another similar solution is given in [6].

VI. Outlines For A Coordinated Braking Protocol

Here we give an outline of protocol for coordinated emergency brake (CEBP). We assume that vehicles cannot be sorted according to deceleration capability as they enter the platoon. Instead, other sorting goals may have priority; such as destination or aerodynamic performance. Potentially, for customer acceptance, small vehicles (e.g. cars) are avoided between or in front of large vehicles to avoid the sensation of being "squashed". A reason for not sorting at all is that vehicles may not have enough coordination or technical capability, such as in the CACC application. Positioning and manoeuvring to sort the joining vehicle, both laterally and longitudinally, may require more automation than is available in application. In this case, vehicles will mainly join from the rear of the platoon. Finally, actively sorting vehicles may also create more disturbance to the rest of the traffic system, than using join from the rear.

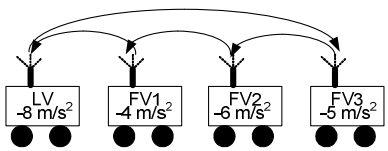

Figure 3: E-brake command from LV. ACK propagates back to LV - from back to front.

CEBP assumes that joined vehicles have decided what deceleration will be actuated in the event of an emergency brake, i.e. an agreed brake strategy. This implies finding cliques of vehicles in platoon that will brake together with a common brake capability. In Figure 3 The brake cliques will be C1=({LV,FV1},-4), C2=({FV2,FV3},-5). The agreed brake capability of cliques increases towards the rear, implying that the last clique will brake the most. Note that this implies a voluntary reduction of deceleration capability.

The actual emergency brake, i.e. actuation of brake strategy, can be initiated by any vehicle in the platoon. It must be ensured that the last vehicle receives the brake command. Intermediate vehicle will potentially also receive the brake command. Vehicles brake according to the previously decided brake strategy. Braking can commence at the last vehicle directly when it receives the message. The braking vehicle then sends out ACK. Preceding vehicles can thus start to brake when the ACK from succeeding cliques arrives. E.g. FV2 cannot brake until ACK is received from FV3 that it has started to brake. This is illustrated in Figure 3. Each vehicle maintains a "brake anyway"-time-out counter. When counter expires, the vehicle will "brake anyway" and following vehicles must detect this with local sensors.

Message sending can be done with event-triggered directed broadcast, i.e. there is a sender and an explicit receiver, but the message may be overheard by other vehicles within the platoon. In this case, a vehicle can prepare its brakes in anticipation of the ACK from succeeding vehicle. Another alternative that will be evaluated in to send the initial message, from brake initiator to last vehicle, with multi-hop. This would increase probability of reception, but latency will scale with the number of hops.

VII. Road test

In the RelCommH project, platooning with three trucks was demonstrated [7]. The controller in the followers was a modified adaptive cruise control that accepted inputs (including braking) from the leader via V2V communication. The aim of the demonstration was to show the difference in performance during hard braking in a platoon using the current standard CAM/DENM protocols and using the Minimal protocol. An ETSI-G5 communication node, with a modified protocol stack to include the Minimal protocol, was used in each truck.

The data update rate of the Minimal protocol was set to 10 Hz. In addition to data from CAM/DENMs (e.g. GPS speed and GPS position), the Minimal protocol provides the data in

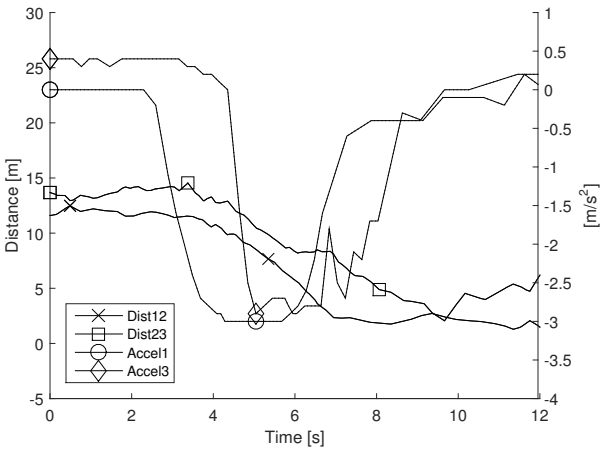

Figure 2: Example of braking with CAM/DENM

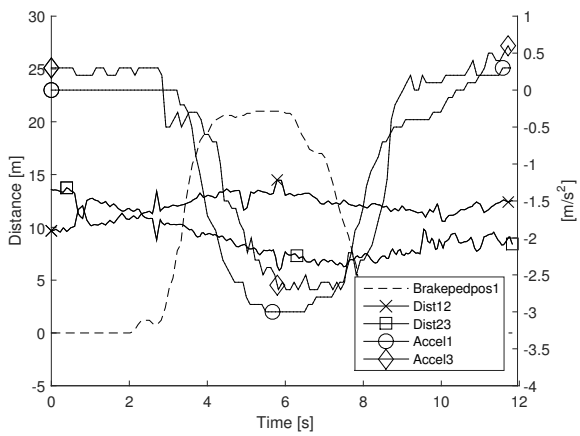

Figure 4: Example of braking with Minimal

TABLE I. Each vehicle, including the leader, transmitted this additional data and the controllers in the following trucks processed this to adapt speed. The tests used COTS GPS-receivers. The inter-vehicle distance was measured with a precision of +/- 2.2 m with a confidence of 95 %.

TABLE I. DATA PROVIDED BY THE MINIMAL PROTOCOL

Data	Description
Vehicle reference speed	Set speed, 0-250 km/h, i.e. cruise control set value.
Vehicle reference acceleration	Planned acceleration -12.5 to 12.5 m/s^2. This is an estimate of the desired acceleration of a vehicle
Brake pedal position	0-100 %. 100 % implies completely depressed pedal. It is an estimate of target retardation.

The goal of the platooning function was to maintain the distance between vehicles that they had prior to braking. Two examples of braking scenarios are given in Figure 2 and Figure 4, one using CAM/DENM only and one using the Minimal protocol. Both use the same speed controllers in the vehicles. Both figures give the acceleration of the first and last vehicle and the inter-vehicle distance of the first and last pair. The two scenarios are commented and the numbers given are approximations from the figures. Braking was done manually and hence differs slightly between scenarios, but in both cases the max deceleration achieved was -3 m/s^2.

The CAM/DENM scenario in Figure 2 starts with the decrease of acceleration in vehicle one (Accel1). The acceleration in vehicle three (Accel3) decreases after a delay of 1.6 s. The distance between the first pair (Dist12) decreases from 12 m to 3 m; and in the second pair (Dist23) from 14 m down to 3 m.

The Minimal scenario in Figure 4 also gives the brake pedal position, i.e. braking starts when it rises from being zero (on the left axis). The acceleration in vehicle one decreases correspondingly albeit with a delay after the brake pedal signal rising, due to pressure build-up in the pneumatic brake system etc. The acceleration in vehicle three decreases after a delay of 0.5 s. Note that the brake pedal position of the first vehicle is available to the other vehicles, i.e. can be used to prepare for braking. The distance between the first pair does not decrease significantly; and in the second pair from 10 m down to 6 m.

VIII. CONCLUSION

In this paper, we have investigated two approaches for information sharing in a vehicle platooning application: a Full platooning protocol and a Minimal protocol. Deficiencies of CAM/DENM based approach were high-lighted. We expect that safety and platooning performance (e.g. minimised gaps and fuel saving) increases with added coordination among platooning vehicles, e.g. a protocol that supports handshake procedure to establishes the presence and identification of followers. Outlines for a coordinated emergency brake protocol are given. We are currently implementing this in PLEXE – a platooning extension [9] of the vehicle simulator Veins.

The Minimal protocol addresses deficiencies of CAM/DENM, e.g. has a fixed update rate and additional data. We have demonstrated the difference between these two protocols in a simplified platooning demo. The Minimal protocol achieved lower latency of brake actuation during a hard brake manoeuvre and hence maintained inter-vehicle distance better.

Further work may be to standardise, e.g. agree among OEMS, a list of data and quality that is sufficient to support platooning. Some messages may need to have particular focus on as low latency as possible, e.g. "Now I am Braking!". Control data messages can potentially contain proprietary data, e.g. unspecified fields for data that only a particular OEM can interpret. However, there may be a risk of confusion and improper usage.

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